

# ***TRANSPORTATION RESEARCH DIGEST***

*June-July 2010*

ARIZONA TRANSPORTATION INSTITUTE

*e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)*

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# ***TRANSPORTATION RESEARCH DIGEST***

## ***ARIZONA TRANSPORTATION INSTITUTE***

*e-mail* [jsemmens@cox.net](mailto:jsemmens@cox.net)

*JUNE-JULY 2010*

TO: TRANSPORTATION PROFESSIONALS, MANAGERS, & POLICY MAKERS

FROM: ARIZONA TRANSPORTATION INSTITUTE

The volume of information on transportation issues, policies, technologies, and related topics is huge. Not even the most well-read professional can keep up with everything that might be useful to know. The *Transportation Research Digest* series is designed to expedite the transmission of information by condensing and summarizing significant documents. Busy professionals or managers may quickly obtain the gist of new developments and determine whether they need to see the full document.

The *Transportation Research Digest* is not meant to present definitive resolutions of scientific or policy controversies, but contributions to the pursuit of knowledge and the debate of issues. The intent is to be comprehensive rather than conclusive on the multitude of issues and topics of concern to those working in the field of transportation. Readers are encouraged to obtain the original document summarized in the *Transportation Research Digest* and subject the content to their own judgment.

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If you would like to obtain the full report upon which a *Transportation Research Digest* summary is based you have several options. Check your local university library. You may want to contact the publisher using the contact information appearing in the *Transportation Research Digest*. Some of the documents are free for the asking. Others can be purchased.

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*Transportation Research Digests* from December 1995 to November 2003 are available on request.

A “Topic” code in the Table of Contents will help readers more quickly identify items of interest. The topic codes are explained in the table below.

<u>Code</u>	<u>Topic</u>	<u>Code</u>	<u>Topic</u>
ADM	Administration	PLAN	Planning
AIRP	Airports	PRIV	Privatization
AVIA	Aviation	RAIL	Railroads
BIKE	Bicycles	RDSO	Roadside
CON	Construction	ROW	Right-of-Way
ECON	Economics	SAFE	Safety
ENV	Environment	STR	Structures
FIN	Finance	TECH	Technology
INOV	Innovations	TOLL	Toll Roads
MAIN	Maintenance	TRAN	Transit
MISC	Miscellaneous	TRF	Traffic
MVD	Motor Vehicle Dept	TRK	Trucking
PAVE	Pavement	VEH	Vehicles

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Thank you.

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e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

**Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs**, NCHRP Report 658 by Keith Molenaar, *et al.* (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; [http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_658.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_658.pdf)) (2010)

### **Highlights**

- A comprehensive risk management approach can help project teams identify, assess, mitigate, and control project risks.

Project cost escalation is a serious problem facing state highway agencies (SHAs). The failure to deliver individual projects and programs within established budgets has a detrimental effect on later programs and causes a loss of faith in the agency's ability to wisely use the public's money. Highway design and construction projects can be extremely complex and are often fraught with uncertainty. However, engineers, project managers, and cost estimators often overlook or fail to recognize project uncertainty early in the project development process. As a result they do not communicate uncertainty and its effect to the stakeholders.

A comprehensive risk management approach can help project teams identify, assess, mitigate, and control project risks. Among the benefits of a comprehensive risk management approach is the ability to generate range estimates early in the project development process and to establish justifiable contingencies that can be resolved throughout the design and construction process. This guidebook presents a systematic process to apply risk analysis tools and management practices to aid SHA management in controlling project cost growth. The Guidebook addresses risk identification, assessment, analysis, mitigation, allocation, and tracking

and control in a manner that is systematically integrated into the organizational structure and culture of SHAs.

### **Risk Management Framework**

The risk management framework described in this Guidebook is based on best practices in design and construction. In the Guidebook, those practices are adapted to the unique needs of highway project development. The iterative risk management framework is described in terms of the project development phases and project complexity. The framework is scalable from small and non-complex projects to large and complex projects. There are five imperative steps to managing project risk.

1. Risk identification is the process of determining which risks might affect the project and documenting their characteristics using such tools as brainstorming and checklists.
2. Risk assessment/analysis involves the quantitative or qualitative analysis that assesses impact and probability of a risk. Risk assessment assists in deriving contingency estimates. Quantitative and qualitative risk analysis procedures are applied to determine the probability and impact of risks.
3. Risk mitigation and planning involves analyzing risk response options (acceptance, avoidance, mitigation, or transference) and deciding how to

approach and plan risk management activities for a project.

4. Risk allocation involves placing responsibility for a risk to a party – typically through a contract. The fundamental tenants of risk allocation include allocating risks to the party best able to manage them, allocating risks in alignment with project goals, and allocating risks to promote team alignment with customer-oriented performance goals.
5. Risk monitoring and control is the capture, analysis, and reporting of project performance, usually as compared to the risk management plan. Risk monitoring and control assists in contingency tracking and resolution.

### **Keys to Success**

Lessons learned from the development of this Guidebook can be summarized in five keys to success for applying risk analysis tools and management practices to control project cost.

1. Employ all steps in the risk management process.
2. Communicate cost uncertainty in project estimates through the use of ranges and/or explicit contingency amounts.
3. Tie risks to cost ranges and contingencies as a means of explaining cost uncertainty to all stakeholders.
4. Develop risk management plans and assign responsibility for resolving each risk.
5. Monitor project threats and opportunities as a means of resolving project contingency.

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e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

*Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts, NCHRP Report 652* by Gary Fick, et al. (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; [http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_652.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_652.pdf)) (2010)

### Highlights

- This project's focus was to identify DOTs that have had extensive experience with time-related I/D projects and identify best practices.

Time-related incentive and disincentive (I/D) provisions have been widely used by U.S. DOTs. The vast majority of these provisions have been successful at accelerating highway construction work, resulting in reduced delays to the traveling public. This project's focus was to identify DOTs that have had extensive experience with time-related I/D projects and identify best practices and lessons learned that will lead to the effective use of time-related I/D provisions.

The following statements provide a concise summary of the impact of time-related I/D provisions on each of the project factors investigated:

- *Cost*—Accelerating construction to achieve earlier completion leads to increased costs. The degree of cost increase depends on many factors. However, market influences from the low bid system used by DOTs are a primary contributor to the ultimate cost of the acceleration paid by the DOTs. Thus, the price paid for acceleration required by I/D provisions is highly influenced by the competitive bidding process. In most cases, this works to the DOTs advantage.

- *Innovation*—I/D provisions motivate contractors to use innovative methods and materials that result in time savings.
- *Contract Administration*—Offering a monetary incentive and disincentive for early or late completion places an emphasis on how contract time is measured. Equally important is an equitable process to determine the time impact of excusable delays.
- *Staffing*—Accelerated work schedules are often accompanied by an increase in number of working hours per week. This increase affects the contractors and DOTs personnel equally. Both contractors and DOTs acknowledge the “burn out” impact created by I/D provisions on their human resources. None of the DOTs and contractors investigated was able to offer any strategies to mitigate this impact.
- *Quality*—Research results did not indicate that time-related I/Ds have a negative impact on quality.
- *Safety*—Contractors and DOTs both indicated that safety practices are unaffected by accelerated work schedules. The safety risk to the public from traveling through construction zones decreases as a result of the shortened time of exposure.

Understanding the impacts of time-related I/D provisions on project factors leads to guidelines for the effective use of I/Ds. A list

of these guidelines for the effective use of I/D provisions includes the following:

- Projects that may be candidates for the inclusion of an I/D provision should be identified early in the project development process. Considering I/D impacts throughout the design process will result in plans and specifications that are well coordinated with I/D milestones.
- When a competitive bidding market exists, DOTs should consider A+B I/D provisions as the preferred method for obtaining accelerated construction at the lowest cost.
- Increase the pool of available bidders by allowing flexibility between the bid award and start of construction.
- Incentives should be capped as a method to reduce the DOT's risk of overpaying for acceleration.
- Measurement of contract time should be based on calendar days as opposed to working days or modified calendar days.
- Incentive rates should use road user cost (RUC) as the basis. Estimates of RUC should be the result of a documented and uniformly applied process.

Improving the state-of-practice for time-related I/D provisions through the implementation of the research findings and proposed guidelines will provide the traveling public with increased value.

### **Terms**

Many different types of time-related I/D provisions are in use or have been used by DOTs. At the most basic level, I/D provisions can be categorized into two groups: A+B and I/D. The primary distinction between these two types is that the contractor determines the

contract duration for an A+B contract while the DOT specifies the contract time for an I/D contract. There are many variations and local modifications on these two basic provisions with state and local laws often impacting the details of time-related provisions. These variations can be confusing because DOTs use similar I/D provisions that have different names.

One common factor shared by every DOT is the use of liquidated damages. The U.S. Code of Federal Regulations (23 CFR 635.127) requires DOTs to establish liquidated damages that, at a minimum, recover the DOTs estimated daily construction engineering costs for overruns in contract time. All I/D provisions are used in conjunction with liquidated damages, meaning that the disincentive portion of an I/D provision consists of more than just the minimum agreed to daily engineering construction costs that will be recovered in the case of late completion of a milestone or project. RUC is the most common item included in both the incentive and disincentive rate for a highway project.

Technically, there is not a difference between a disincentive and liquidated damages. They are both contractual provisions in which both parties agree to the payment of a monetary sum that is estimated fairly and would prove to be difficult or impossible to quantify after the fact. However, in practice, there is a considerable difference between liquidated damages and disincentives because the addition of RUC significantly increases the agreed to monetary sum that is applied for late completion. For clarity, the guidance contained in this report makes the assumption that liquidated damages are based solely on the recovery of DOT daily construction engineering costs and are dealt with independently of I/D provisions that include RUC.

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*e-mail* [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

***Biofuel Co-Product Uses for Pavement Geo-Materials Stabilization*** by Kasthurirangan Gopalakrishnan, Halil Ceylan, and Sunghwan Kim, Institute for Transportation, Iowa State University, 2711 South Loop Drive, Suite 4700, Ames, IA 50010-8664 (Iowa Highway Research Board, Iowa Department of Transportation, 800 Lincoln Way, Ames, IA 50010; [http://www.intrans.iastate.edu/reports/Ceylan\\_Bio\\_report.pdf](http://www.intrans.iastate.edu/reports/Ceylan_Bio_report.pdf)) (Apr 2010)

### **Highlights**

- Utilizing biofuel coproducts as a soil stabilizer appears to be a viable use of these bio-based products.

Sustainable use of biomass as a renewable source to produce energy could be an alternative solution to the problems of the cost of fossil-based energy and global warming. The production and use of biofuels as renewable energy has increased. Biofuels produced from plant biomass creates not only biofuels or ethanol, but also co-products that contain lignin, modified lignin, and lignin derivatives. The use of lignin in soil stabilization has been studied over the past decades. However, most of the previous lignin-related soil stabilization studies investigated sulfite lignins (lignosulfonates) derived from the paper industry, while the lignins obtained from biofuel or ethanol production are sulfur-free. Newer uses of biomass-derived lignin need to be developed to provide additional revenue streams to improve the economics of the bio-based products and the bioenergy business. The present study aims to investigate the innovative utilization of biofuel coproducts (BCPs) containing sulfur-free lignin in pavement soil stabilization.

Laboratory tests were conducted to evaluate the strength performance and the moisture susceptibility of two types of BCP-treated soil samples to compare to the performance of untreated and traditional

stabilizer-treated (fly ash) soil samples. Two types of BCPs investigated were (1) a liquid type BCP with higher lignin content (co-product A) and (2) a powder type BCP with lower lignin content (co-product B). Various additive combinations (co-product A + fly ash, co-products A + B, etc.) were also evaluated as alternatives to stand-alone additives. The unconfined compression strength (UCS) experimental test was used to evaluate strength performance. Atterberg limits and standard Proctor compaction tests were also conducted as engineering properties tests. Additive and moisture contents and curing periods were incorporated as variables into the strength property test factorial. The experimental test program for evaluating moisture susceptibility consisted of UCS tests after “dry” and “wet” conditioning as well as visual observations of soaked specimens (so-called soaking tests). The UCS tests were conducted on both dry and wet specimens to evaluate the strength loss due to moisture intrusion. Each specimen was also fully soaked in water over a period of time to examine how long it could withstand moisture damage and whether it would fail due to moisture effects.

Performance test results indicate that BCPs are effective in stabilizing the Iowa Class 10 soil classified as CL or A-6(8). Moisture susceptibility test results indicate that the BCPs also have excellent resistance to moisture degradation. Co-product A with higher lignin content is more effective at providing

resistance to moisture damage than co-product B with lower lignin content and traditional additive (fly ash). The use of combined additives (co-product A + fly ash, coproducts A + B) could be a promising alternative to the use of co-product A alone to obtain strengths and moisture resistance comparable to traditional additive (fly ash).

Utilizing BCPs as a soil stabilizer appears to be a viable use of these bio-based products. Because much more BCP is disposed of rather than utilized, making more productive use of BCPs would have considerable benefits for sustainable development. BCPs used in this experiment demonstrated excellent potential for stabilizing low-quality materials for use in pavement foundation systems. These products could be used to stabilize existing subgrade materials to provide a stable working platform and to improve the strength of undesirable soil materials for use as the load-bearing layer within the pavement system. From an economic perspective, the change to renewable energy from fossil-based energy could result in less production and higher costs of fly ash, which is a byproduct from coal-fired power plants. However, this change could also result in higher production and lower costs of BCPs, making them comparable to traditional soil stabilizers. While fly ash has the potential to leach heavy metals that would result in soil

contamination, BCPs could be beneficially used without adversely impacting the environment because the feedstock of biofuels and co-products is natural biomass and they are considered to be biodegradable. However, this needs to be further researched.

Future research is needed to evaluate the freeze-thaw durability and for resilient modulus characterization of BCP-modified soils. In addition, the long-term performance of these BCPs should be evaluated under actual field conditions and traffic loadings. Because only one soil type was investigated in this study, any future work should investigate the use of lignin-based BCPs for a variety of soils that are being used as pavement subgrade and base layers in highway infrastructure systems. Considering the wide range of pavement-related applications in which modified lignins have already been used, such as concrete admixtures, dust suppressants, and potentially pavement base layer treatment agents and joint and crack sealants, the utilization of BCPs containing sulfur-free lignin in these applications should be investigated in the future. Newer uses of BCPs in pavement-related applications could not only provide additional revenue streams to improve the economics of biorefineries, but could also serve to establish green road infrastructures.

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e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

***No Tax Increase for Federal Transportation Programs?*** by Ronald Utt (Heritage Foundation, 214 Massachusetts Ave NE, Washington DC 20002-4999; phone 202.546.4400; <http://www.heritage.org/Contact-Heritage>) (April 19, 2010)

### **Highlights**

- Americans can expect a future of greater congestion and time-consuming travel as government prioritizes a lifestyle transformation over a level of economic vitality reliant upon timely and cost-effective mobility.

Advocates of more federal spending for highways and transit note that the federal fuel tax (currently 18.3 cents per gallon of gasoline) has not been raised since 1993 and that the 17-year freeze has limited the financial resources of the highway trust fund and its ability to fund transportation investments. Combined with sluggish growth in fuel usage and cost increases for the labor and materials used in transportation infrastructure projects, this leads spending advocates to contend that available federal resources fall well short of what is needed to maintain and expand the current surface transportation system.

Similar complaints occur in states where state fuel taxes (ranging from 8 cents per gallon in Alaska to 37.5 cents in Washington State) have been similarly frozen for many years. Efforts to increase them have been met by the same motorist resistance that has prevented the federal fuel tax from being raised.

Although several reasons explain motorists' reluctance to spend more on a dysfunctional system, a major reason is a lack of confidence in the ability of those who run federal and state transportation programs to use the money wisely.

A case in point is what happened in 2004 when Representative Don Young (R-AK), then chairman of the House Transportation and Infrastructure Committee (T&I), wanted to increase the gas tax to increase spending. President Bush opposed him, as did most motorists and their elected representatives, in large part because Young became nationally notorious for his intention to spend more than \$1 billion of these new taxes for two Bridges to Nowhere in his home state.

One would have thought that there was a lesson to be learned in this epic fiasco, but if so, it has escaped the current crop of transportation officials in Congress and the Administration who have since embraced a policy that one journalist labeled "A Bridge to the 19th Century." Current T&I Committee chairman James Oberstar (D-MN) introduced legislation to spend \$500 billion on transportation, a substantial portion of which would fund trains, trolleys, and bicycles and discourage automobile use.

Secretary of Transportation Ray LaHood has also made it clear on several occasions that he intends to "coerce" people out of their cars and onto sidewalks, bicycles, and streetcars. He also wants a housing policy that encourages people to live in crowded, high-density communities where everything is close by and automobiles are unneeded, much as Americans lived in, say, 1895.

Since taking office, LaHood has advocated or implemented a series of policies to achieve these goals by favoring transit and "non-motorized" transportation instead of cars.

In doing so, LaHood fulfills what one author of a recent study of such behavior describes as “the authenticity hoax in full throat: a dopey nostalgia for a non-existent past, a one-sided suspicion of the modern world, and stagnant and reactionary politics masquerading as something personally meaningful and socially progressive.” The following have been among LaHood’s initiatives since his Senate confirmation in 2009:

Responding to complaints raised at a May 2009 National Press Club speech that his proposed shift of money from cars to transit involved meddling in individual decisions, LaHood said, “About everything we do around here is government intrusion in peoples lives. ... It is a way to coerce people out of their cars. Yeah.”

In response to press requests to define his livability goal, LaHood stated in September 2009 that “livability means being able to take your kids to school, go to work, see a doctor, drop by the grocery or post office, go out to dinner and a movie, and play with your kids in a park, all without having to get in your car.”

Also in September 2009, the Obama Administration created a task force comprised of the Department of Housing and Urban Development (HUD), the Department of Transportation (DOT), and the Environmental Protection Agency to develop a livability agenda that includes more transportation choices (i.e., more trolleys and busses). Task force sub-goals include encouraging transit-oriented development, safeguarding rural landscapes, and promoting walkable neighborhoods.

In November 2009, FTA announced that it is expanding the radius from one-half mile to three miles of a public transportation facility within which bicycle and pedestrian projects would be eligible for FTA funding, thereby making more such projects eligible for federal funding.

In December 2009, LaHood announced that all applications for Transportation Infrastructure Finance and Innovation Act loans would have to be redone and resubmitted to reflect the Administration’s interest in “livability.” Approved projects should link transportation with housing and quality-of-life issues. (See second item above for LaHood’s definition of livability.)

In January 2010, LaHood rescinded existing Federal Transit Administration (FTA) guidelines that required rigorous cost-benefit analysis relying on measurable mobility benefits to justify federal investment in transit projects. These standards were replaced by more subjective benefits that considered non-transportation goals such as economic development and the environment, thereby making more transit projects eligible for federal funding.

In March, LaHood proposed letting states and localities circumvent certain DOT regulations governing transportation projects if instead they obey HUD rules on high-poverty areas, including job training opportunities. In effect, transportation spending need not be about transportation.

At a March “Bicycle Summit,” LaHood said: “Today, I want to announce a sea change. People across America who value bicycling should have a voice when it comes to transportation planning. This is the end of favoring motorized transportation at the expense of non-motorized.”

It is apparent from a review of White House and congressional transportation policies that enhanced mobility and congestion mitigation is of little interest to current leadership. Instead, Americans can expect a future of greater congestion and time-consuming travel as government prioritizes a lifestyle transformation over a level of economic vitality reliant upon timely and cost-effective mobility.

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e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

***Improving Accuracy in Household and External Travel Surveys*** by David Pearson, Edwin Hard, Stephen Farnsworth, Tim Forrest, Debbie Spillane, Mark Ojah, Katie Womack, Sharon Boxill, and Carol Lewis, Texas Transportation Institute, The Texas A&M University System, College Station, Texas 77843-3135 (Texas Department of Transportation, Research and Technology Implementation Office, P.O. Box 5080, Austin, TX 78763-5080; <http://tti.tamu.edu/documents/0-5711-1.pdf>) (Jan 2010)

### **Highlights**

- Recommendations for how to improve survey accuracy are outlined.

This research has examined a number of aspects of household and external travel surveys. It has included a review of the practice of these surveys outside Texas and how Texas practice compares relative to a number of measures.

### ***Household Surveys***

This research has found that household surveys as practiced in Texas are comparable to those done in other parts of the nation. Areas examined in this research included household participation, sampling frames, non-response, incentives, weighting and expansion of survey data, survey techniques, quality control, and survey geocoding. In-depth examination and analyses using survey data from Texas were done in evaluating the household survey sampling frame, non-response in household surveys, and proxy reporting in household surveys. The following recommendations are made for household surveys in Texas.

- Vendors should be required to document how the sample of households is selected and the randomness of the procedure maintained. Specifically, the documentation should include how cell

- phones are handled in the recruitment and data retrieval phases.
- Vendors should be required to document the disposition of all phone calls in the recruitment and retrieval phases and provide a computation of the response rate for the household survey.
- Vendors should be encouraged to use mixed modes for household recruitment and data retrieval. Mixed modes that should be considered include telephone, mail, and internet.
- Vendors should be required to incorporate into the survey design and execution a follow-up survey directed at households that have refused to participate and households that could not be contacted by phone. The method for this survey is mail based recruitment with data retrieval subject to the method best suited to the participants. This recommendation may be done on an experimental basis initially with a follow-up evaluation to assess the benefits versus the costs involved.
- Vendors should be allowed to have proxy reporting for all minors in a household. Minors are defined as individuals under the age of 16. Proxy reporting for persons over the age of 15 should be limited to not exceed 20% of those individuals participating in the household survey.

- Analysis of household surveys should be expanded to include an evaluation of the trips per person for individuals being represented by proxy versus individuals responding personally. The results of that evaluation should be incorporated into the development of recommended trip production rates for use in travel demand models.
- Additional research is recommended to examine the feasibility of combining un-weighted household surveys from different areas and using the combined data to develop representative household trip rates for urban areas that do not have a household survey.

#### *External Surveys*

This research has found that external surveys as practiced in Texas are comparable to those executed in other parts of the nation. Areas examined in this research included survey methodology, technology, survey design, survey sample size, survey conduct times, vehicle classification counts, survey geocoding, survey quality control and training, survey data entry and checks, and the expansion of the survey data. The following recommendations are made for external surveys in Texas.

- Vendors should be required to provide all vehicle classifications counts by direction in 15-minute increments using the FHWA Scheme F for classifying vehicles. All data should be submitted in Excel files. Vendors should be required to use tablet personal computers as the primary means for conducting roadside intercept surveys with paper surveys available as a backup.
- Vendors should be required to maintain a log for each external survey that documents the number of interviewers being used and the name of the on-site supervisor for each hour the survey is in progress.
- Vendors should be prohibited from using the project manager as a site supervisor on a full time basis. The project supervisor can be allowed to serve as site supervisor in a temporary relief capacity.
- Vendors should be prohibited from using interactive GIS maps for geocoding at the time of interview unless it can be shown to TxDOT's satisfaction that the geocoding can be achieved within the time frame of the survey and the technical capability to accomplish the geocoding is possessed by all the vendor's surveyors.
- Vendors should be required to calibrate the AVC counters being used at all external survey sites and provide documentation of same.
- Vendors should be required to video tape vehicles in both directions passing through the survey site, manually classified the vehicles by hour for the time period surveys are conducted, and provide the data including video tapes to TxDOT as part of the requirements for each external station surveyed. The minimum sample requirement for commercial vehicles at external stations should be 70 useable commercial vehicle surveys or 25 percent of the commercial vehicles traversing the survey site during the time period the surveys are conducted. This minimum should be set for usable commercial vehicle surveys.

# **TRANSPORTATION RESEARCH DIGEST**

## **ARIZONA TRANSPORTATION INSTITUTE**

e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

*An Assessment of Traffic Safety in Urban Deer Herd Management Zones in Iowa* by Konstantina Gkritza, Michael Baird, and Zachary Hans, Center for Transportation Research and Education, Iowa State University, 2711 South Loop Drive, Suite 4700, Ames, IA 50010-8664 (Iowa Highway Research Board, Iowa Department of Transportation, 800 Lincoln Way, Ames, IA 50010; [http://www.intrans.iastate.edu/reports/Gkritza\\_Deer\\_Crashes\\_rpt.pdf](http://www.intrans.iastate.edu/reports/Gkritza_Deer_Crashes_rpt.pdf)) (Feb 2010)

### **Highlights**

- The authors recommend efforts to reduce deer density adjacent to roads and developed land.

The main objective of this study was to investigate the relationship between deer-vehicle collisions, deer density, and land use in select urban deer management zones in Iowa over the period 2002 to 2007. Three urban areas in Iowa that have deer management plans in place were selected for this study: Cedar Rapids, Dubuque, and Iowa City. Three different databases were used in this study: first, deer population counts from 1997 to 2008 were acquired from the Iowa DNR; second, deer carcass removal locations on primary roads and corresponding carcass counts were provided by the Iowa Department of Transportation (Iowa DOT); and last, deer-vehicle crash data from 2002 to 2007 were gathered from the Iowa DOT. To begin, the deer-vehicle crash and deer carcass removal counts were compared at the county level. Further, the authors estimated econometric models to investigate the factors that influence the frequency and severity of deer-vehicle crashes in these zones. Results from this study can assist in a better assessment of traffic safety in urban deer herd management zones and could be of interest to transportation, ecology, and deer management communities.

Overall, the number of deer carcasses removed on the primary roads in the counties

of the study was greater than the number of reported deer-vehicle crashes on those roads. These differences can be attributed to a number of reasons, including variability in data reporting and data collection practices. In addition, high rates of crash underreporting were found on major routes that carry high volumes of traffic.

This study also showed that multiple factors with corresponding outcomes affect deer-vehicle crashes in urban management zones. The authors found that deer density rather than deer herd size is a more significant predictor of the frequency of deer-vehicle crashes in urban deer management zones. Further, the frequency of deer-vehicle crashes was higher in zones with a higher percentage of residential and commercial acreage, which confirms the adverse safety impacts of human migration into deer habitats. While a reduction in deer density may not be attainable in all zones, the authors recommend efforts to reduce deer density adjacent to roads and developed land.

The severity outcomes and the number of injuries that resulted from a deer-vehicle collision were determined as a function of crash-, road-, and land-use-specific factors. Overall, the frequency of deer-vehicle injuries increased over the study period in the three urban deer management areas, which may be attributed to an increase in the vehicle miles traveled and a higher deer population. While the frequency of crashes is higher on roads with

a posted speed limit below 55 miles per hour, these crashes are less likely to result in injury, probably because of lower impact speeds that result in a less severe outcome. Further, the expected frequency of deer-vehicle injuries was lower on roads with wider shoulders. The fact that the expected frequency of crashes is higher on undivided roads may suggest the potential benefits of wider shoulders on these roads.

It is also interesting to note the significant predictive values of non-roadway factors (land use characteristics) in both the frequency of deer-vehicle crashes and corresponding injury outcome. The identified roadway and non-roadway factors could be useful for identifying locations on the transportation system that significantly impact deer species and safety and for determining appropriate mitigation countermeasures.

### **Recommendations**

*Data collection:* The lack of accurate and consistent reporting of deer carcass removals and deer-vehicle crashes as well as the absence of deer population counts for some zones in some years of the study period are important limitations of these data. In addition, deer carcasses are mainly collected on primary roadways, and very little carcass data are reported on the secondary roadways in Iowa. Not considering the secondary roadway system leaves many deer-vehicle crashes unaccounted for. It is desirable to improve the consistency and accuracy of deer carcass and deer-vehicle collision data collection methods and practices. Providing maintenance crews with global positioning system (GPS) units to record the location of deer carcasses could improve the accuracy of carcass reporting.

*Countermeasures:* The literature review showed that different countermeasures have

been implemented over time to reduce the occurrence of deer-vehicle crashes. Many countermeasures, such as deer whistles and deer flagging models, have been proven ineffective. A few countermeasures, such as wildlife crossings and deer fencing, have been proven effective (but at a higher cost), while some countermeasures (including herd management) require more research to evaluate their effectiveness. The implementation of countermeasures should be considered in terms of effectiveness, level of investment, and maintenance costs. Countermeasure locations are critical to their effectiveness. These countermeasures must also be maintained properly to sustain their effectiveness. Moreover, continuous monitoring can detect changes in the effectiveness of countermeasures due to changes in driver behavior or animal adaptation. Last, findings should be properly documented for future reference.

*Urban Planning and Management Implications:* Results from this study illustrated the impact of urban development on deer habitat and densities and, subsequently, on deer-vehicle crashes. Urban planners and officials need to account for these interactions early during urban planning efforts, determine how to minimize impacts to wildlife during planning, and monitor future trends. The effectiveness of special herd management hunts in urban areas cannot be fully assessed based solely on their effect on traffic safety. In order for an accurate assessment to be made, reductions in property and crop damage are other important measures of effectiveness that need to be taken into account. This could be achieved through a comprehensive, multidisciplinary study on all measures of effectiveness.

# **TRANSPORTATION RESEARCH DIGEST**

## **ARIZONA TRANSPORTATION INSTITUTE**

e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

*Median Intersection Design for Rural High-Speed Divided Highways, NCHRP Report 650* by T.H. Maze, *et al.* (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; [http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_650.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_650.pdf)) (2010)

### **Highlights**

- Treatments for improving safety are evaluated.

Median-separated highways provide distinct benefits over undivided roadways. Medians separate opposing traffic, provide a recovery area for out-of-control vehicles, provide a stopping area in case of emergencies, allow space for speed changes and storage of left-turning and U-turning vehicles, minimize headlight glare, and provide width for future lanes. In addition, rural multilane divided highways (expressways) with partial or no access control and low access densities provide safety performance and travel time benefits nearly equal to rural Interstates at a lower cost due to the fact that expressways can be built without purchasing full access rights and without constructing as many overhead bridges and interchanges.

Because of the expected safety and mobility benefits and lower costs of rural expressways (as compared with freeways), several states have built or are building expressway networks and plan to add additional miles to their systems. Most additions involve twinning an existing undivided two-lane highway, but in some cases, the expansion may involve the construction of a new corridor on separate right-of-way (bypasses) or other alignment improvements (i.e., curve flattening or realigning to be more consistent with the natural topography). However, several state transportation agencies (STAs) have seen the

expected safety benefits of expressways diminished by increased at-grade intersection crashes and increased intersection crash severity. Research has shown that the percentage of total expressway crashes which occur at two-way stop-controlled (TWSC) intersections increases as the mainline traffic volumes increase and that all intersection crashes increase and become more severe as minor roadway volumes increase.

The majority of crashes at TWSC expressway intersections tend to be right-angle crashes. The most problematic of these (with respect to severity) tend to be those occurring in the far-side intersection (i.e., after the minor road driver has traveled through the median). An initial response to this type of crash is to assume that the minor roadway driver did not recognize the intersection and ran the stop sign, but examination of crash records in many states have shown that this is very infrequently the cause of expressway intersection crashes. More commonly, it has been found that minor road drivers fail to select a safe gap in the mainline traffic stream (i.e., misjudge the time-to-arrival of expressway vehicles) when entering the intersection from a stopped condition. After addressing potential design issues such as insufficient sight distance, the traditional approach to addressing safety problems at expressway intersections is to improve the traffic-control devices, implement traffic signal control, and eventually construct an overpass or interchange. However, traffic signals do not always improve safety: they may only change the crash type distribution. In general, traffic

signals in rural areas are discouraged for several reasons including violation of driver expectations and difficulty in servicing and maintaining signals in remote locations. The final alternative is to build an interchange at the intersection. The construction of an interchange reduces the cost advantage of building an expressway as compared with building a freeway, and the mix of at-grade intersections and interchanges tends to violate driver expectations.

Therefore, the purpose of this project was to investigate alternative safety improvements at rural expressway intersections, to identify their relative effectiveness (if data was available), and to report any experiential information from those agencies who have tried the alternative. Although the traditional safety improvement path is from stop control to signal control to interchange construction, there are a myriad of non-traditional improvements that can be deployed to improve safety at a lower cost. These treatments can be categorized into three fundamental types—conflict-point management, gap selection aids, and intersection recognition devices—which are described within the report and have been shown (but not proven) to improve safety.

Although there is no proof that reducing the number of conflict points will reduce crashes, it makes sense that eliminating or reducing severe types of conflict points (e.g., crossing path) by replacing them with less severe conflict points (i.e., merge and diverge) will reduce crash severity. A traditional TWSC expressway intersection has 42 conflict points. This number can be reduced through the use of J-turn intersections, offset T-intersections, or jughandle intersections. Although conflict-

point management strategies can be expensive to construct, they tend to offer the greatest crash reduction potential.

Improving intersection sight distance or assisting the minor road driver with gap selection aids are meant to help the minor road driver determine whether a gap is safe to accept. Low-cost examples include median acceleration lanes and offset turning lanes.

Providing advance intersection warning to all drivers approaching an intersection (i.e., intersection recognition devices) is meant to make approaching drivers more aware of the intersection so that they might be more prepared to react accordingly. Intersection recognition devices can be divided into two categories: those for the minor road and those for the mainline. Two mainline intersection recognition devices that alert the mainline driver to the presence of intersections having an increased crash risk are discussed and evaluated.

When attempting to develop design guidance and traffic-control standards for intersection safety countermeasures, two predominant problems arise:

1. All are relatively new treatments and the safety improvement impacts of each are still unproven.
2. An expressway is generally a hybrid design between a freeway and a two-lane roadway. Therefore, a roadway designer looking for guidance on expressway intersections is forced to look in several locations for design guidance within the AASHTO Green Book. There are two possible solutions to this dilemma: the first is to reorganize the Green Book, and the other is to develop a separate manual on expressway and expressway intersection design.

# **TRANSPORTATION RESEARCH DIGEST**

## **ARIZONA TRANSPORTATION INSTITUTE**

e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

***Evaluation and Repair Procedures for Precast/Prestressed Concrete Girders with Longitudinal Cracking in the Web***, NCHRP Report 654 by Maher K. Tadros, *et al.* (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; [http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_654.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_654.pdf)) (2010)

### **Highlights**

- The primary objective of the work conducted in this research project was to establish a user's manual for the acceptance, repair, or rejection of precast/prestressed concrete girders with longitudinal web cracking.

Precast/prestressed concrete bridge girders are widely used in the United States. Longitudinal web cracks, often called end zone cracks, at the ends of pretensioned concrete girders are commonly observed at the time of strand detensioning, an event generally referred to as prestress transfer. During the last two decades, especially with the use of relatively high concrete strength, deep girders, and high levels of prestress, these cracks have become more prevalent. Longitudinal cracks will always develop in prestressed girders if the vertical bursting stresses generated by prestress transfer are greater than the tensile capacity of the concrete. Conventional reinforcement is generally placed to keep the cracks within acceptable width.

In practice, there is no consistent understanding of the impact of end zone cracking on the strength and durability of the girders. Thus, the decisions made by bridge owners vary from doing nothing to total rejection of the girders. Other reactions include debonding of strands at the girder ends, limiting prestress levels, reducing allowable compression stress at the time of prestress transfer, injecting grout into the cracks, and

coating the girders' ends with sealants. There is no consensus among owners on the level of tolerance to these longitudinal cracks.

Concerns regarding end zone cracks are based on the possibility of having reduced structural capacity and future durability issues from strand and bar corrosion. End zone cracks that run parallel with and intersect the prestressing strands, reflecting strand locations, could cause debonding. This would result in an increase in the transfer and development lengths, which may consequently reduce the shear and flexural capacity of the girder. Wide reflective cracks along the strands that are exposed to chloride solutions may cause strand deterioration. Therefore, a thorough understanding was needed to determine whether longitudinal web cracks are of structural significance. If these cracks are not structurally significant, an understanding of whether they reduce durability was required.

Published guidelines regarding acceptance and repair criteria of prestressed concrete girders consider many types of cracking that may be reported but do not adequately address the uniqueness of end zone cracking. Also, most of these guidelines are greatly influenced by the criteria developed for flexural cracking in beams, which is fundamentally different in cause and effects from end zone cracking. For example, flexural cracks in beams tend to grow in width and depth with the application of superimposed loads. On the contrary, end zone cracks tend to become narrower with the application of

superimposed loads and the development of long term prestress losses.

The primary objective of the work conducted in this research project was to establish a user's manual for the acceptance, repair, or rejection of precast/prestressed concrete girders with longitudinal web cracking. The research resulted in establishing the following proposed cracking limits:

- Cracks narrower than 0.012 in. may be left unrepaired.
- Cracks ranging from 0.012 to 0.025 in. should be repaired by filling the cracks with approved specialty cementitious materials, and the end 4 ft of the girder side faces should be coated with an approved sealant. Recommendations are given about several products currently available for this repair and about repair procedure.
- Cracks ranging from 0.025 to 0.050 in. should be filled with either epoxy injection or cementitious patching material, depending on crack width, and then the surface should be coated with a sealant.
- For girders exhibiting cracks wider than 0.05 in., the research team recommends that the girder be rejected. For such girders, the research team believes that the cause of cracking may be beyond just the expected bursting force effects. If the owner wishes to reconsider these girders, it is recommended that a thorough structural analysis for the cause and effect of the cracking be conducted and appropriate measures taken.

Based on full-scale experimental observations and previous research, it was found that end zone cracks can be effectively controlled by concentrating the reinforcement as near the girder ends as allowed by requirements for concrete cover to reinforcement and minimum reinforcement spacing. Further, reinforcement should be gradually reduced within a distance approximately equal to half of the member depth in order to prevent cracks from reopening beyond the zone of concentrated reinforcement. It is thus recommended that the required reinforcement amount in the current AASHTO LRFD Bridge Design Specifications be retained, but the distribution of the reinforcement changed. The reinforcement is still determined for a bursting force of 4% of the prestressing force and a stress limit of 20 ksi. But, at least 50% of that steel should be placed in the end  $h/8$  of the member (where  $h$  is total girder depth). The full amount of bursting steel should be placed in the end  $h/2$  of the member (not  $h/4$ ) as currently specified. Anchorage of the steel into the top and bottom flanges is most critical for the bars in the  $h/8$  zone as the steel stress rapidly diminishes beyond that zone. Even in the  $h/8$  zone, it is not necessary to develop bars for yield strength as this reinforcement is only for crack control and would experience its highest possible stress in the early stages of girder production and handling. End zone reinforcement should be anchored into the top and bottom flanges to develop at 30 ksi. Recommended reinforcement details are given in this report.

# **TRANSPORTATION RESEARCH DIGEST**

## **ARIZONA TRANSPORTATION INSTITUTE**

e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

**Defining Success: The Case against Rail Transit** by Randall O'Toole (Cato Institute, 1000 Massachusetts Ave, NW, Washington, DC 20001-5403; Phone (202) 842-0200; <http://www.cato.org/pubs/pas/pa663.pdf>) (Mar 24, 2010)

### **Highlights**

- No system passes all of the measures of success and few pass any of the tests.

Since 1970, American cities have spent \$100 billion constructing rail transit systems, and many billions more operating those systems. The agencies that spend taxpayer dollars building these lines call them successful even when they go an average of 40% over budget and, in many cases, carry an insignificant number of riders.

This Policy Analysis uses the latest government data on scores of rail transit systems to evaluate the systems' value and usefulness to the public using different tests:

- *Profitability*: Do rail fares cover operating costs?
- *Ridership*: Do new rail lines significantly increase transit ridership?
- *Cost-Effectiveness*: Are new rail lines less expensive to operate than buses providing service at similar frequencies and speeds?
- *The Economic Development Test*: Do new rail lines truly stimulate economic development?
- *The Transportation Network Test*: Do rail lines add to or place stresses upon existing transportation networks?

<b>Profitability and Ridership of Rail Transit Lines</b>						
<i>Urban Area (Agency)</i>	<i>Mode</i>	<i>Fare% of Operating Cost</i>	<i>Fare % of Total Cost</i>	<i>Loss per Trip</i>	<i>Occupancy per Car</i>	<i>Total Weekday Riders</i>
Albuquerque	CR	10%	4%	\$34.78	Unknown	4,700
Atlanta	HR	31%	10%	\$5.34	25.6	266,869
Baltimore	HR	22%	5%	\$18.63	12.9	46,362
Baltimore	LR	19%	7%	\$11.52	19.3	25,560
Boston	HR	58%	39%	\$1.63	25.1	515,175
Boston	LR	59%	37%	\$1.75	32.6	256,128
Boston (Downeaster)	CR	47%	46%	\$16.36	19.1	1,281
Boston (MBTA)	CR	54%	30%	\$8.26	33.9	143,498
Buffalo	LR	18%	4%	\$20.81	18.1	19,743
Charlotte	LR	17%	3%	\$20.14	27.3	11,678
Chicago (CTA)	HR	46%	26%	\$2.86	17.6	641,783
Chicago (Metra)	CR	44%	29%	\$7.74	41.1	278,855
Chicago (N. Indiana)	CR	50%	30%	\$10.88	33.5	13,897
Cleveland	HR	25%	15%	\$4.53	26.5	25,360
Cleveland	LR	20%	11%	\$7.05	24.1	10,703
Dallas	LR	16%	4%	\$18.50	28.9	65,757
Dallas-Ft. Worth	CR	9%	2%	\$46.14	24.0	9,730
Denver	LR	53%	13%	\$6.85	14.3	67,196
Detroit	AG	8%	3%	\$17.50	6.1	5,898
Houston	LR	33%	16%	\$3.67	33.7	40,567
Jacksonville	AG	6%	1%	\$49.40	0.9	1,736
Kenosha	SC	6%	3%	\$7.05	3.7	162

Little Rock	SC	8%	2%	\$26.47	3.9	317
Los Angeles	CR	50%	26%	\$15.33	41.9	47,210
Los Angeles	HR	33%	4%	\$15.76	36.3	134,665
Los Angeles	LR	19%	6%	\$11.14	34.8	134,327
Memphis	SC	22%	6%	\$13.17	1.8	2,829
Miami	AG	0%	0%	\$8.07	7.7	27,333
Miami	CR	17%	7%	\$29.16	42.8	13,228
Miami	HR	16%	6%	\$12.38	19.9	62,307
Minneapolis	LR	38%	11%	\$6.92	31	30,518
Nashville	CR	15%	8%	\$41.03	15.1	667
New Orleans	SC	31%	18%	\$4.28	10.9	12,298
New York (CY)	CR	12%	5%	\$63.03	14.9	1,986
New York (Hudson-Bergen)	LR	17%	8%	\$12.62	24.2	48,291
New York (LIRR)	CR	48%	34%	\$9.96	29.1	342,754
New York, (Metro North)	CR	59%	43%	\$8.19	36.9	285,613
New York (MTA)	HR	67%	43%	\$1.21	28.8	7,822,158
New York (NJ Transit)	CR	56%	36%	\$8.97	38.1	300,900
New York (PATH)	HR	45%	25%	\$3.88	29.4	279,937
New York (Staten Island)	HR	20%	18%	\$3.47	19	27,739
NY/Philadelphia (NJ Transit)	LR	26%	26%	\$31.11	21	20,440
Philadelphia (PAT CO)	HR	50%	40%	\$3.07	22.1	36,184
Philadelphia (PennDOT)	CR	50%	40%	\$22.98	16.7	1,509
Philadelphia (SEPTA)	CR	57%	39%	\$5.56	29.5	117,056
Philadelphia (SEPTA)	HR	53%	24%	\$2.70	25.6	305,353
Philadelphia (SEPTA)	LR	44%	33%	\$1.79	18.9	95,946
Pittsburgh	LR	16%	7%	\$13.07	18	6,784
Portland	LR	37%	10%	\$7.44	28.2	118,970
Sacramento	LR	27%	10%	\$8.03	20.1	52,686
Salt Lake City	CR	15%	3%	\$52.19	23.5	7,228
Salt Lake City	LR	36%	8%	\$7.21	24.5	48,664
San Diego	LR	56%	15%	\$4.58	25.9	113,635
San Diego (North County)	CR	39%	13%	\$26.94	37.6	6,180
San Diego (North County)	LR	9%	2%	\$44.36	48.9	31,252
San Francisco	CC	47%	46%	\$3.87	19.1	20,530
San Francisco	CR	46%	22%	\$12.47	40.6	36,421
San Francisco	LR	19%	10%	\$4.53	22.8	159,405
San Francisco (BART)	HR	65%	20%	\$10.68	21.6	384,231
San Jose	LR	16%	5%	\$17.46	16.2	33,043
San Jose (Altamont)	CR	38%	23%	\$18.57	48.4	3,191
San Juan	HR	18%	5%	\$23.65	13.6	29,974
Seattle	CR	26%	6%	\$45.37	61.2	9,914
Seattle	SC	11%	5%	\$14.24	6.7	1,295
Seattle (Tacoma)	SC	0%	0%	\$11.60	9.8	3,018
St. Louis	LR	30%	8%	\$9.85	21.4	57,384
Tampa	SC	30%	22%	\$4.64	8.9	1,025
Washington	HR	61%	21%	\$6.09	23.5	971,490
Washington (MARC)	CR	35%	22%	\$14.86	47.4	31,216
Washington (VRT)	CR	46%	29%	\$15.14	59.1	14,508
National average/total	AG	3%	1%	\$11.73	6.4	34,967
National average/total	CR	50%	32%	\$9.80	35.7	1,670,542
National average/total	HR	59%	28%	\$2.60	25.7	11,549,587
National average/total	LR	29%	11%	\$6.91	24.4	1,448,677
National average/total	SC	23%	10%	\$7.48	7.5	20,944
National average/total	AU	53%	27%	\$3.82	28.5	14,746,247

Source: 2008 National Transit Database (Federal Transit Administration). AG=automated guideway, CC=cable car, CR=commuter rail, HR=heavy rail, LT=light rail, SC=street car

# **TRANSPORTATION RESEARCH DIGEST**

## **ARIZONA TRANSPORTATION INSTITUTE**

e-mail [jsemmens@cox.net](mailto:jsemmens@cox.net)

JUNE-JULY 2010

***Consistent Signal Timing Strategies at Intersections with Wide Medians to Improve Efficiency and Safety*** by S.R. Sunkari, P. Songchitruksa, X. Zeng, K.N. Balke, K.O. Obeng-Boampong, Texas Transportation Institute, The Texas A&M University System, College Station, Texas 77843-3135 (Texas Department of Transportation, Research and Technology Implementation Office, P.O. Box 5080, Austin, TX 78763-5080; <ftp://ftp.dot.state.tx.us/pub/txdot-info/rti/psr/6176.pdf>) (Feb 2010)

### **Highlights**

- This research project provides recommendations regarding the operational strategy to use at intersections with wide medians.

Texas Department of Transportation (TxDOT) engineers currently do not have formal guidelines to design and operate intersections with wide medians. A wide median is defined as wider than 60 feet. Lack of formal guidelines results in inconsistent design and operation of such intersections, which has sometimes resulted in an operation that did not meet driver expectation. Usually strategies are developed for peak conditions, but such strategies may not be very efficient for off-peak conditions. Inefficient operations that do not meet driver expectancy can result in an increase in motorists' non-compliance at traffic signals, which is unsafe. The Texas Transportation Institute (TTI) conducted a one-year research project to evaluate operations at intersections with wide medians and provide guidelines to operate such intersections in a consistent manner.

Researchers received input from 18 districts on problems and strategies with wide median intersections. Factors that affect the operations of intersections with wide medians include:

1. Median width: Median width has an impact on the storage capacity in the interior. At intersections with medians of 100 feet or

less, appropriate strategies should be selected to keep the interior clear.

2. Number of lanes in the interior: This factor has an impact on the number of phases that can be used for the interior movement. In cases where an intersection has a single lane in each direction in the interior, only a single phase can be applied for all traffic in the interior. If however the interior has an exclusive left-turn lane in the interior, two separate phases can be used to give more flexibility in the operations.

3. Approach speed: High approach speeds require an appropriate strategy that provides dilemma zone protection and the appropriate detection configuration. Low approach speeds only require stop bar detection to provide safe operations.

4. Available right of way on a major street: One of the strategies uses an exclusive arterial left-turn phase to control vehicles entering the median. However in urban or suburban areas, major street approaches may not have enough right of way to have an exclusive left-turn lane. This has an impact on the strategy that the operator can choose.

5. Volumes on major movements as well as minor movements: The strategies to be used depend on the volume levels at the intersections. High volumes on major movements require a strategy that does not create long queues on a major street. Similarly high volume levels on minor movements, which include minor street movement as well

as major street left-turn movement, can block a median and back up traffic into its upstream intersection.

Based on the interviews with the districts and factors identified, eight strategies were identified to be evaluated in this project.

a) Diamond phasing - Three phase, Four phase, and Two phase, and b) Non-Diamond phasing - Two phase, Split phase (with and without trailing overlap), and Major street phase (with and without arterial left-turn phase).

VISSIM simulation modeling was used to simulate the strategies. A library of volume scenarios was created. Major movement volumes were increased from 250 vehicles/hour to 1250 vehicles/hour. Minor movements, which included minor street volumes and arterial left-turn movements, were modified as a percentage of the major movement ranging from 10 to 30 percent. A total of 45 sets of volume scenarios was created. This library of volume scenarios was applied to all the strategies. Each volume scenario was repeated six times with different random seed numbers. A total of almost 10,000 simulation runs was made in this project to evaluate these strategies.

The observations made by TTI researchers were similar to the experiences of TxDOT engineers across the state. However some findings from the simulation runs were unique:

- Trailing green overlaps, which have been used at most intersections with wide medians, tend to increase overall delay. TTI researchers recommend that these overlaps should be used sparingly.
- The Two-phase strategy appeared to be more efficient than any other strategy.

This was particularly the case during low-volume conditions. However two-phase operations at intersections with a median width of 100 feet or less tended to fill up the median with turning traffic. For such intersections, use a four-phase operation or use the strategy with an arterial left-turn phase.

- When the arterial left-turn phase is used, it is recommended to use lead-lag phasing and to lag the heavier left-turn phase.

Based on the findings of the simulation study, TTI researchers made recommendations about strategies to operate intersections with wide medians. These recommendations are in a tabular format and are based on local geometry and volume conditions. The table recommends a combination of compatible strategies to use at a certain location for differing volume conditions.

This research project provides recommendations regarding the operational strategy to use at intersections with wide medians. These recommendations are based on geometric as well as traffic patterns at an intersection. Researchers recommend that more than one strategy be used at a particular intersection if there is a significant change in volume patterns from peak periods to off-peak periods. Such an operational philosophy will result in the implementation of a proper strategy that will be appropriate for traffic conditions and will meet motorists' expectations, improving intersection efficiency and safety.